Global Warming and Building Energy Consumption: An Annotated Bibliography

Paul Baer, Marilyn Brown, Matt Cox, and Jeff Hubbs*
School of Public Policy
Georgia Institute of Technology

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*Please direct information about corrections or omissions to:
Marilyn.Brown@pubpolicy.gatech.edu

Introduction

This document is an annotated bibliography of selected literature addressing the broad topic of the response of energy consumption in buildings to global climate change. Because the objective of the underlying research is to better characterize the components of the National Energy Modeling System (NEMS) that will be affected by climate change, some studies are included that are relevant even though they do not directly address climate change. We do not include any literature published before 1990.

The citation for each work is followed by a description edited from the work's abstract where an abstract is present.

Tags

The studies that are included have been classified with one or more of six “tags,” as follows (note that the search terms beginning with X allow you to find the tag without finding all other locations of the word)

Tag Name	**Icon**	**Description**	**Search for this text in document**
Observation/Projection		Studies that analyze variations in energy demand and energy costs based on observed variation in weather and climate and/or based on projected future changes using models parameterized with historical data	XOBS
Behavior		Studies examining changes in people’s behavior in regard to energy consumption in response to variations in weather and climate	XBEH
Pricing and Incentives		Studies of the effects of price or other incentives on energy demand, as it informs projected responses to energy market impacts of climate change or climate policy	XPRI
Equipment		Studies of the impacts of changes in climatic environment on the performance of energy-using equipment (including fuel switching) and the building envelope	XEQP
Population Shifts		Studies of historical or projected population shifts in response to climatic or other factors that may inform projections of future demand under changing climate	XPOP
Regional Analysis		Studies of regional variations in energy demand that may inform projections of future demand under changing climatic conditions	XREG

XOBS XREG

Aebischer, B., Catenazzi, G., & Jakob, M. (2007). Impact of climate change on thermal comfort, heating and cooling energy demand in Europe, 859–870. Retrieved from https://edit.ethz.ch/cepe/publications/Aebischer_5_110.pdf

> Evidence is provided regarding the increasing relevance of thermal discomfort in terms of overheating, due to both building retrofits and climate change. Further, possible changes in heating and cooling energy demand over the next 30 years are explored for two climate variants: mean annual temperatures remaining constant and a second case in which temperatures increase until 2035 by +1°C in winter and +2°C in summer. The possible impacts on the CO_2 emissions in different European locations are evaluated considering the CO_2 intensity of the heating fuels, the market penetration of electric heating, and the CO_2 intensity of electricity production. For much of Europe, increases in cooling energy demand due to global warming will be outweighed by reductions in the need for heating energy. Depending on the generation mix in particular countries, the net effect on CO_2 emissions may be an increase even where overall demand for delivered energy is reduced. Strategies and measures in the building sector to minimize possible negative impacts of climate change on energy demand for heating and cooling are discussed.

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Akpinar-Ferrand, E., & Singh, A. (2010). Modeling increased demand of energy for air conditioners and consequent CO2 emissions to minimize health risks due to climate change in India. *Environmental Science & Policy*, *13*(8), 702–712. doi:10.1016/j.envsci.2010.09.009

> Developing countries situated mostly in latitudes that are projected for the highest climate change impact in the twenty-first century will also have a predictable increase in demand on energy sources. India presents us with a unique opportunity to study this phenomenon in a large developing country. This study finds that climate adaptation policies of India should consider the significance of air conditioners (A/Cs) in mitigation of human vulnerability due to unpredictable weather events such as heat waves. However, the energy demand due to air conditioning usage alone will be in the range of an extra ~750,000 GWh to ~1,350,000 GWh with a 3.7 °C increase in surface temperatures under different population scenarios and increasing incomes by the year 2100. We project that residential A/C usage by 2100 will result in CO_2 emissions of 592 Tg to 1064 Tg. This is significant given that India's total contribution to global CO_2 emissions in 2009 was measured at 1670 Tg and country's residential and commercial electricity consumption in 2007 was estimated at 145,000 GWh.

XOBS XBEH XREG

Amato, A. D., Ruth, M., Kirshen, P., & Horwitz, J. (2005). Regional Energy Demand Responses to Climate Change: Methodology and Application to the Commonwealth Of Massachusetts. *Climatic Change*, *71*(1-2), 175–201. doi:10.1007/s10584-005-5931-2

Regional energy demand responses to climate change are explored by assessing temperature-sensitive energy demand in Massachusetts. The study employs a two-step estimation and modeling procedure, evaluating the historic temperature sensitivity of residential and commercial demand for electricity and heating fuels using a degree-day methodology. When controlling for socioeconomic factors, degree-day variables have significant explanatory power in describing historic changes in residential and commercial energy demands. Potential future energy demand responses to scenarios of climate change are then assessed.

XOBS

Apadula, F., Bassini, A., Elli, A., & Scapin, S. (2012). Relationships between meteorological variables and monthly electricity demand. *Applied Energy*, *98*, 346–356. doi:10.1016/j.apenergy.2012.03.053

Electricity demand depends on climatic condition and the influence of weather has been widely reported in the past. The main purpose of this study is to analyze the effect of the meteorological variability on the monthly electricity demand in Italy. Temperature, wind speed, relative humidity and cloud cover are considered; the calendar effect is also taken into account. A multiple linear regression model based on calendar and weather related variables is developed to study the relationships between meteorological variables and electricity demand as well as to predict the monthly electricity demand up to 1 month ahead. The model has been extensively tested over the period 1994–2009 using different combinations of the weather related variables. Accuracies obtained are quite similar and range between 0.85% and 0.89%. Temperature turns out to be the most important variable. According to the month considered, a specific combination of the weather related variables can give the lowest Mean Absolute Percentage Error (MAPE) but differences are usually small. Good results for the summer months are obtained using Heat Index to calculate the Cooling Degree-Days; the cloud cover has a major influence from February to April.

When demand forecasts are performed using the predicted meteorological variables, an overall accuracy (MAPE) around 1.3% is obtained over the period 1994–2009.

The proposed model clearly identifies the influence of the weather conditions on the aggregated national electricity demand.

XOBS

Argonne National Laboratory (ANL). (2008). Climate Change Impacts on the Electric Power System in the Western United States. Argonne, IL. Retrieved from http://www.dis.anl.gov/news/WECC_ClimateChange.html

In this analysis, we use results from regional climate models to examine the impacts of projected changes in temperature and precipitation on the development and operations of the power system in the Western United States. A warmer climate, in combination with drier conditions, is projected to increase the NPV of fuel purchases and variable O&M costs above the base case by about $61 billion through 2050. This increase is attributable mainly to higher utilization rates of relatively expensive peaking technologies, such as natural gas-fired gas turbines. However, if the climate becomes wetter than the current climate, but still warmer, production cost increases are expected to be smaller: approximately $25 billion above the base case over the entire analysis period. Another aspect of climate change that would increase the cost of energy production, but is not included in the current analysis, is the increased pressure on utility fuel prices. As the demand for electricity swells, consumption of fossil fuels at power plants will also increase. The price of natural gas is particularly sensitive to supply and demand balances.

XOBS XEQP XREG

Artmann, N., Gyalistras, D., Manz, H., & Heiselberg, P. (2008). Impact of climate warming on passive night cooling potential. *Building Research & Information*, *36*(2), 111–128. Retrieved from 10.1080/09613210701621919

In order to quantify the impact of climate warming on the night-time ventilation cooling potential in Europe, eight representative locations across a latitudinal transect were considered. Based on a degree-hours method, site-specific regression models were developed to predict the climatic cooling potential (CCP) from minimum daily air temperature (T_{min}). CCP was computed for present conditions using measured T_{min} data from the European Climate Assessment (ECA) database. Possible time-dependent changes in CCP were assessed for 1990–2100. Time-dependent, site-specific T_{min} scenarios were constructed from 30 Regional Climate Model simulated data sets. Under both emissions scenarios and across all locations and seasons, CCP was found to decrease substantially by the end of the 21st century. For the six Central and Northern European locations CCP was found to decrease in summer by 20–50%. For the two Southern European locations, future CCP was found to become negligible during the summer and to decrease by 20–55% during the spring and the autumn. The study clearly shows that night-time cooling potential will cease to be sufficient to ensure thermal comfort in many Southern and Central European buildings. In Central and Northern Europe, a significant passive cooling potential is likely to remain, at least for the next few decades. Upper and lower bound estimates for future CCP were found to diverge strongly in the course of the 21st century, suggesting the need for flexible building design and for risk assessments that account for a wide range of emissions scenarios and uncertainty in climate model results.

XPRI

Atkinson, J. G. B., Jackson, T., & Mullings-Smith, E. (2009). Market influence on the low carbon energy refurbishment of existing multi-residential buildings. *Energy Policy*, *37*(7), 2582–2593. doi:http://dx.doi.org/10.1016/j.enpol.2009.02.025

This paper explores the relationship between the energy market, the political and regulatory context, and energy design decisions for existing multi-residential buildings to determine what form the energy market landscape would take if tailored to encourage low-carbon solutions. The links between market dynamics, government strategies, and building designs are mapped to understand the steps that achieve carbon reduction from building operation. This is achieved using a model that takes financial and energy components with market and design variables to provide net present cost and annual carbon outputs. The financial component applies discounted cash flow analysis over the building lifespan, with discount rates reflecting contractual characteristics; the carbon component uses Standard Assessment Procedure 2005. A scenario approach is adopted to test alternative strategies selected to encourage low carbon solutions in two residential and two office designs. The results show that the forward assumption of energy price escalation is the most influential factor on energy investment, together with the expected differentiation between the escalation of gas and electricity prices. Using this, and other influencing factors, the research reveals trends and strategies that will achieve mainstream application of energy efficiency and microgeneration technologies, and reduce carbon emissions in the existing multi-residential sector.

XPRI

Auffhammer, M., & Mansur, E. T. (2012). Measuring Climatic Impacts on Energy Expenditures : A Review of the Empirical Literature.

This paper reviews the literature on the relationship between climate and the energy sector. In particular, we primarily discuss empirical papers published in peer-reviewed economics journals focusing on how climate affects energy expenditures and consumption. Climate will affect energy consumption by changing how consumers respond to short run weather shocks (the intensive margin) as well has how people will adapt in the long run (the extensive margin). Along the intensive margin, further research that uses household-level panel data of energy consumption may help identify how consumers around the world respond to weather shocks. Research on technology adoption, e.g. air conditioners, will further our understanding of the extensive margin adjustments and their costs.

XOBS XEQP

Aydinalp, M., Ismet Ugursal, V., & Fung, A. S. (2002). Modeling of the appliance, lighting, and space-cooling energy consumptions in the residential sector using neural networks. *Applied Energy*, *71*(2), 87–110. doi:10.1016/S0306-2619(01)00049-6

Two methods are currently used to model residential energy consumption at the national or regional level: the engineering method and the conditional demand analysis method. Another potentially feasible method to model residential energy consumption is the neural network (NN) method. Using the NN method, it is possible to determine causal relationships amongst a large number of parameters, such as occur in the energy consumption patterns in the residential sector. A review of the published literature indicates that the NN method has not been used or tested for housing-sector energy consumption modeling. A NN based energy consumption model is being developed for the Canadian residential sector. This paper presents the NN methodology used in developing the appliances, lighting, and space-cooling component of the model, the accuracy of its predictions, and some sample results.

XOBS XEQP XREG

Baxter, L. W., & Calandri, K. (1992). Global warming and electricity demand: A study of California. *Energy Policy*, 20(3).

> In this paper we estimate changes in California's annual electricity use and peak demand by 2010 under two global warming scenarios. We use each warming scenario to produce an electricity demand projection with end-use energy models, our analysis focuses on the heating and cooling of buildings and the pumping and transport of water for farms and cities. The results suggest global warming has a moderate effect on electricity demand. Under our worst scenario, a 1.9°C increase, we project Statewide electricity requirements will increase by about 7500 GWh (2.6%) and 2400 MW (3.7%). We conclude discussion with thoughts on the implications a warmer world may have for energy forecasters and resource planners.

XOBS XBEH

Bessec, M., & Fouquau, J. (2008). The non-linear link between electricity consumption and temperature in Europe: A threshold panel approach. *Energy Economics*, *30*(5), 2705–2721. doi:10.1016/j.eneco.2008.02.003

> This paper investigates the relationship between electricity demand and temperature in the European Union. We address this issue by means of a panel threshold regression model on 15 European countries over the last two decades. Our results confirm the non-linearity of the link between electricity consumption and temperature found in more limited geographical areas in previous studies. By distinguishing between North and South countries, we also find that this non-linear pattern is more pronounced in the warm countries. Finally, rolling regressions show that the sensitivity of electricity consumption to temperature in summer has increased in the recent period.

XBEH XEQP

Brager, G. S., & De Dear, R. (2000). A standard for natural ventilation. *ASHRAE Journal*, *42*(10), 21. Retrieved from http://www.library.gatech.edu:2048/login?url=http://search.proquest.com/docview/220477549?accountid=11107

> This article argues that adequate scientific basis now exists to amend the thermal comfort standards ASHRAE Standard 55 to include a more "adaptive" field-based alternative for application to naturally ventilated buildings. Such a proposal reflects findings that thermal preference in such buildings varies widely from predictions made by the present laboratory-based standard. The article suggests that one possible reason for this discrepancy may be that the heat-balance model of thermal comfort underlying the present standard cannot account for the complex ways people interact with their environments, modify their behaviors, or gradually adapt their expectations to match their surroundings.

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Brown, M. A. (2010). The Multiple Policy Dimensions of Carbon Management: Mitigation, Adaptation, and Geo-engineering. *Carbon Management*, *1*(1), 27–33.

> This paper examines the multiple policy dimensions of carbon management: mitigation, adaptation, and geo-engineering. Owing to their distinct advantages and disadvantages, an optimal climate strategy should consider all three perspectives of carbon

management. On the one hand, effective adaptation reduces the costs of inadequate mitigation efforts. A resilient, adaptive system is better able to withstand external shocks, thus the stabilization level of GHG atmospheric concentrations that avoids 'dangerous impacts' is higher in an adaptable world. On the other hand, effective mitigation reduces the need for investments in adaptation, because the magnitude of global climate change is moderated. Having an effective geo-engineering plan is an important risk-management strategy for the possibility of failed mitigation and adaptation.

XBEH
Brown, S., & Walker, G. (2008). Understanding heat wave vulnerability in nursing and residential homes. *Building Research & Information*, *36*(4), 363–372. doi:10.1080/09613210802076427

Epidemiological research has shown that in England and Wales older people in nursing and residential homes are among those most vulnerable to the impacts of hot weather. It is argued that there is a real need to deepen the understanding of the everyday settings in which people experience heat wave conditions and the ways in which various social, cultural, institutional, and infrastructural considerations may contribute to creating vulnerability and limiting the possibilities of short- or long-term adaptation. Epidemiological evidence is reviewed to establish who is vulnerable in hot weather. This is followed by an examination of how an ethnographic and qualitative approach can be used to provide a deeper insight into how those vulnerabilities are constructed. The provisional findings of a small pilot study are presented, along with a number of the problems encountered, in order to demonstrate the type of data that can be accessed through a qualitative methodology, and how the routines and practices of everyday life may be implicated in the reproduction of vulnerability.

XOBS XBEH XEQP
Chow, D. H. C., & Levermore, G. J. (2010). The effects of future climate change on heating and cooling demands in office buildings in the UK. *Building Services Engineering Research & Technology*, *31*(4), 307–323. Retrieved from 10.1177/0143624410371284

This paper aims to provide a comprehensive study and understanding as to how various different office buildings in the UK will cope with climate change, especially how climate change will affect the heating and cooling loads, as well as the associated CO_2 emissions as a result of meeting the thermal demands. Using a second-order model, this study simulates an office room for three main UK locations, Heathrow (London), Manchester and Edinburgh, under respective climate change data for the 2020s, 2050s, and 2080s, comparing their thermal energy consumptions with current weather data. Apart from testing the office room with different orientations, construction thermal 'weight' and different future climate scenarios, the office room was also made to comply with various Building Regulations, which determine the permitted maximum U-values and glazing area of the external envelope, and the type of glazing used. This represents the office buildings currently in the building stock in the UK, and the analyses conducted are to examine how each will perform in the 21^{st} century. The results from this study would be useful for building designers to know which aspects will affect energy consumption and thus CO_2 emissions most in the future, and what should be done with the existing building stock, where most buildings were built to with higher U-values and single glazing, to make them perform efficiently in the face of a warmer climate.

XPOP XREG

Curtis, K. J., & Schneider, A. (2011). Understanding the demographic implications of climate change: estimates of localized population predictions under future scenarios of sea-level rise. *Population and Environment*, *33*(1), 28–54. doi:10.1007/s11111-011-0136-2

> This paper estimates that 20 million people in the United States will be affected by sea level rise by 2030 in selected regions that represent a range of sociodemographic characteristics and corresponding risks of vulnerability. The results show that the impact of sea-level rise extends beyond the directly impacted counties due to migration networks that link inland and coastal areas and their populations. Substantial rates of population growth and migration are serious considerations for developing mitigation, adaptation, and planning strategies, and for future research on the social, demographic, and political dimensions of climate change.

XOBS

Darmstadter, J. (1993). Climate Change Impacts on the Energy Sector and Possible Adjustments in the Mink Region. *Climatic Change*, *24*(1-2), 117–129. doi:10.1007/BF01091479

> The discussion reviews the prevailing pattern of energy demand and supply in the MINK states, speculates on the region's long-term energy future in the absence and presence of greenhouse warming, and, in the latter case, considers energy sector adaptation to such a prospect. Climate-sensitive energydemand is dominated by heating and cooling in various sectors of the regional economy (around 20% of regional energy consumption) and by such agricultural applications as irrigation pumping and crop drying (around 5%). A climate-sensitive energysupply issue of some importance is the region's partial dependence on hydroelectric capacity in the upper Missouri river basin. The analysis finds that, unlike the rather significant impacts likely to be experienced by other sectors of the regional economy, the hypothesized warming trend will translate into only small net increases in energy demand; and that technological possibilities and policy measures are available to mute any serious climatic effects on the energy sector.

XOBS XEQP

Day, A. R., Jones, P. G., & Maidment, G. G. (2009). Forecasting future cooling demand in London. *Energy and Buildings*, *41*(9), 942–948. doi:http://dx.doi.org/10.1016/j.enbuild.2009.04.001

Cooling of buildings in the UK is responsible for around 15 TWh per year of energy demand, largely powered by electricity with highly related CO_2 emissions. The Greater London Authority wished to understand the potential impact of London's growing need for cooling on UK CO_2 emissions in the period up to 2030. This paper describes a model developed to analyze the cooling requirements for London's key building stock and assess how these would be affected by change in system mix, improvements in system efficiencies, and by varying degrees of climate change. The analysis showed that, if left unchecked, the growth in active cooling systems in London could lead to a doubling of CO_2 emissions from this source by 2030. This growth will be due to increase in building stock, increase in market share of cooling systems, and climate change. The last of these is difficult to predict, but by itself could add 260,000–360,000 tonnes of CO_2 emissions by 2030. This increase can be strongly mitigated, or even offset, by improvements in system efficiency. The difference between no efficiency improvements, and an assumed 1–3% annual efficiency improvement is around 340,000 tonnes by 2030.

XOBS XBEH

Day, T. (2006). *Degree-days: theory and application* (p. 106). London: The Chartered Institution of Building Services Engineers.

Degree-days are a tool that can be used in the assessment and analysis of weather related energy consumption in buildings. They have their origins in agricultural research where knowledge of variation in outdoor air temperature is important, and the concept is readily transferable to building energy. Essentially degree-days are a summation of the differences between the outdoor temperature and some reference (or base) temperature over a specified time period. A key issue in the application of degree-days is the definition of the base temperature, which, in buildings, relates to the energy balance of the building and system. This can apply to both heating and cooling systems, which leads to the dual concepts of heating and cooling degree-days. This TM replaces previous guidance given in section 18 of the 1986 edition of CIBSE Guide B [CIBSE 1986] and Fuel Efficiency Booklet 7 [Energy Efficiency Office 1993]. It provides a detailed explanation of the concepts described above, and sets out the fundamental theory upon which building related degree-days are based. It demonstrates the ways in which degree-days can be applied, and provides some of the historical backdrop to these uses. This TM can be read alongside Carbon Trust Guide 004 (formerly GPG 310): Degree days for energy management – a practical introduction [Carbon Trust 2006], which serves as an introduction to their use. The material in this document provides deeper insights into the degree-day concept, but can be used in conjunction with CTG 004 for advanced building energy analysis.

XOBS XPOP

Diaz, H. F., & Holle, R. L. (1984). The Relative Effects of U.S. Population Shifts (1930-1980) on Potential Heating, Cooling and Water Demand. *Journal of Climate and Applied Meteorology*, *23*(March), 445–448.

> The effects on potential heating, cooling, and water demand induced by the shift and growth of population from cooler and wetter regions of the country to warmer and drier areas were examined. Heating and cooling degree day totals for each of the 48 contiguous states were weighted by population to obtain national totals using U.S. Census figures starting with the 1930 Census. The shift in population from the Northeast and Midwest to the South and Southwest United States has resulted in relatively lower heating but greater cooling demand on a national basis in the 1980s as compared with the results obtained using the 1930 Census. The increase in population in the arid West has increased the region's sensitivity to precipitation, and hence streamflow fluctuations.

XEQP

EIA. (2013). Air Conditioning in Nearly 100 Million Homes. Retrieved from http://www.eia.gov/consumption/residential/reports/2009/air-conditioning.cfm

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EIA. (2005). Impacts of Temperature Variation on Energy Demand in Buildings. *Issues in Focus*, *AEO2005*. Retrieved from http://www.eia.gov/oiaf/aeo/otheranalysis/aeo_2005analysispapers/vedb.html

XOBS

EIA. (2009). Residential Energy Consumption Survey. *Consumption and Efficiency*. Retrieved from http://www.eia.gov/consumption/residential/

XOBS

Elkhafif, M. A. T. (1996). Energy Economics An iterative approach for weather-correcting energy consumption data. *Energy Economics*, *18*, 221–230.

> Energy consumption data are influenced by the weather conditions. The use of unadjusted energy data in analysis and forecasting could give misleading and erroneous results. In this paper a new iterative econometric technique is developed to correct for abnormal weather conditions in published energy consumption data. The technique is applied to sectorial natural gas sales data for the province of Ontario, Canada. The empirical results reveal that following the methods, available in the literature results in weather-corrected data that still contain a significant portion of the abnormal weather impact. In addition, the study suggests that residential and commercial natural gas data require more weather correction than the data for the industrial sector.

XBEH XPRI XEQP

Energy Modeling Forum. (2011). *Energy Efficiency and Climate Change Mitigation* (Vol. I). Stanford, CA. Retrieved from http://emf.stanford.edu/files/pubs/22530/summary25.pdf

> This report summarizes discussions of the modeling results on the role of energy efficiency improvements in global climate change mitigation strategies. The working group is planning an additional volume of individually contributed papers on most of the models in the study.

XOBS XPRI

Engle, R. F., Granger, C. W. J., Rice, J., Weiss, A., & Engle, F. (1986). Semiparametric Estimates of the Relation Between Weather and Electricity. *Journal of the American Statistical Association*, *81*(394), 310–320.

> A nonlinear relationship between electricity sales and temperature is estimated using a semiparametric regression procedure that easily allows linear transformations of the data. This accommodates introduction of covariates, timing adjustments due to the actual billing schedules, and serial correlation. The procedure is an extension of smoothing splines with the smoothness parameter estimated from minimization of the generalized cross-validation criterion introduced by Craven and Wahba (1979). Estimates are presented for residential sales for four electric utilities and are compared with models that represent the weather using only heating and cooling degree days or with piecewise linear splines.

XOBS XPRI XREG

Eskeland, G. S., & Mideksa, T. K. (2010). Electricity demand in a changing climate. *Mitigation and Adaptation Strategies for Global Change*, *15*(8), 877–897. doi:10.1007/s11027-010-9246-x

> Our interest is in electricity demand and the temperature aspects of climate change. Electricity consumption is of interest both from the perspectives of adaptation to climate change and emission reductions. We study the relationship between European electricity consumption and outdoor temperature and other variables, using a panel data set of 31 countries. Apart from providing a rare quantitative window onto adaptation, the study contributes demand system parameters with respect to price and income. The results suggest that weather has a statistically significant effect on electricity demand, with effects that are of plausible magnitude. In a simulation of climate change for the next 100 years—other factors held constant—we find that the demand for heating will decrease in Northern Europe while the demand for cooling will increase in Southern Europe. In countries like Cyprus, Greece, Italy, Malta, Spain, and Turkey the net effect of increased cooling outweighs decreased heating consumption whereas in most of Europe the opposite holds. The largest estimated partial impact in 20%, which predicted increase in adaptive consumption for Turkey and decrease in adaptive consumption for Latvia. Estimated elasticities with respect to income and price are 0.8 and minus 0.2 respectively: plausible in the light of the literature. As a discussion item, we add that electricity consumption changes due to temperature change likely will be small compared to those due to other factors, such as changes in income, demography and technology. The study does not include effects of climate change other than through electricity consumption.

XOBS XEQP XPRI

Executive Office of the President. (2013). *Economic Benefits of Increasing Electric Grid Resilience To Weather Outages.*

XOBS

Fiorini, A., & Sileo, A. (2011). *A note on asymmetries in heating degree- days and natural gas consumption dependence structure. An Archimedean copula framework on the Italian system*. Milano. Retrieved from www.iefe.unibocconi.it

> The aim of this paper is to verify whether heating degree-days are a consistent linear predictor of natural gas consumption. A case study was developed on a monthly average of heating degree-days and monthly (residential and total) natural gas consumption. Estimation results on alternative Archimedean copulas confirm that there is not sufficient evidence supporting a symmetric association with respect to the range of values that the variables can jointly assume.

XOBS XPOP XREG

Franco, G. (2005). *Climate Change Impacts and Adaptation in California.*

> This paper presents a short review of the existing literature on climate change impacts and adaptation options for California. At the global scale, there is a scientific consensus that climate is changing and that the increased concentration of greenhouses gases in the atmosphere are responsible for these changes. California will get warmer in the future, but the level of warming is not known. With respect to precipitation, there is no consensus on how California would be affected, but it is clear that the warming would result in increased runoff in the winter season and decreased runoff in the spring and summer. Human adaptation to climate change in the state may be costly. Ecosystems, one of the most precious state resources, could be severely affected not only by climate change, but also by other stressors such as increased urbanization. Because of the thermal inertia of the Earth, our climate will continue to warm and, for this reason, the identification of adaptation options should be a state priority. Finally, this paper suggests that scientific research should be an integral part of the state overall strategy for how to deal with climate change.

XOBS XREG

Franco, G., & Sanstad, A. H. (2008). Climate change and electricity demand in California. *Climatic Change*, *87*(S1), 139–151. doi:10.1007/s10584-007-9364-y

> The potential effect of climate change on California's electric power system is an issue of growing interest and importance to the state's policy makers. Climate change-induced temperature increases may exacerbate existing stresses on this system. Detailed recent data are used to estimate the relationships between temperature and both electricity consumption and peak demand at a sample of locations around California. These results are combined with new projections of regional climate change affecting California obtained by statistically downscaling recent global projections generated by two general circulation models, to yield estimates of potential impacts of future temperature changes on electricity consumption and peak demand, and illustrative economic cost estimates in several cases. Both current and prospective coping strategies, and priorities for further research, are summarized.

XOBS XBEH XEQP XREG

Gram-Hanssen, K. (2010). Residential heat comfort practices: understanding users. *Building Research & Information*, *38*(2), 175–186. doi:10.1080/09613210903541527

> A detailed analysis of empirical evidence from different households living in similar buildings in a suburb of Copenhagen, Denmark, shows significant variation in energy consumption due to different usage patterns of both the house and its heating system. An analysis using practice–theory finds that technologies, embodied habits, knowledge, and meanings are the main components in the understanding of both what holds this practice together as a collectively shared practice and the different socio-material configurations of each of the individual households.

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Greenstone, M. (2011). Climate Change, Mortality, and Adaptation: Evidence from Annual Fluctuations in Weather in the US †, *3*(October), 152–185.

> Using random year-to-year variation in temperature, we document the relationship between daily temperatures and annual mortality rates and daily temperatures and annual residential energy consumption. Both relationships exhibit nonlinearities, with significant increases at the extremes of the temperature distribution. The application of these results to "business as usual" climate predictions indicates that by the end of the century climate change will lead to increases of 3 percent in the age-adjusted mortality rate and 11 percent in annual residential energy consumption. These estimates likely overstate the long-run costs, because climate change will unfold gradually allowing individuals to engage in a wider set of adaptations. (JEL I12, Q41, Q54)

XOBS

Gupta, E. (2012). Global warming and electricity demand in the rapidly growing city of Delhi: A semi-parametric variable coefficient approach. *Energy Economics*, *34*(5), 1407–1421. doi:10.1016/j.eneco.2012.04.014

> This paper estimates the climate sensitivity of electricity demand in Delhi using daily data on electricity demand and apparent temperature for the period 2000–09. The study adopts a semi-parametric variable coefficient model in order to investigate the impact of climatic factors on electricity demand. As evident from previous studies, electricity demand is a U-shaped function of temperature. We find the rising part of the temperature–electricity curve to become more pronounced over time implying an increase in cooling demand per unit increase in summer temperatures. The study therefore predicts the adverse effects of climate change on electricity demand to be asymmetrically distributed in different seasons in the future, resulting in a serious disequilibrium in the hot months.

XPOP

Gutmann, M. P., & Field, V. (2010). Katrina in Historical Context: Environment and Migration in the U.S. *Population and environment*, *31*(1-3), 3–19. doi:10.1007/s11111-009-0088-y

> This paper seeks to demonstrate that the kinds of environmental factors exemplified by Hurricane Katrina and the Dust Bowl are dwarfed in importance and frequency by the other ways that environment has both impeded and assisted the forces of migration. The authors enumerate four types of environmental influence on migration in the U.S.: 1) environmental calamities, including floods, hurricanes, earthquakes, and tornadoes, 2) environmental hardships and their obverse, short-term environmental benefits, including both drought and short periods of favorable weather, 3) environmental amenities, including warmth, sun, and proximity to water or mountains, and 4) environmental barriers and their management, including heat, air conditioning, flood control, drainage, and irrigation.

XOBS

Hadley, S., Erickson, D., Hernandez, J. L., & Thompson, S. (2004). "Future U.S. Energy Use for 2000-2025 as Computed with Temperatures from a Global Climate Prediction Model and Energy Demand Model". In United States Association for Energy Economics (Ed.), *Proceedings of the 24th Annual North American Conference of the USAEE*. Cleveland, OH. Retrieved from http://www.iaee.org/documents/washington/Stan_Hadley.pdf

> Presentation slides describe various results from NEMS modeling including changes to energy consumption for indoor heating and cooling by end use and by region, economic impacts, and carbon emissions.

XOBS XEQP

Hadley, S. W., Erickson, D. J., Hernandez, J. L., Broniak, C. T., & Blasing, T. J. (2006). Responses of energy use to climate change: A climate modeling study. *Geophysical Research Letters*, *33*(17), L17703. doi:10.1029/2006GL026652

> Using a general-circulation climate model to drive an energy-use model, the authors projected changes in USA energy-use and in corresponding fossil-fuel CO_2 emissions through year 2025 for a low (1.2°C) and a high (3.4°C) temperature response to CO_2 doubling. The low-ΔT scenario had a cumulative (2003–2025) energy increase of 1.09 quadrillion Btu (quads) for cooling/heating demand. Northeastern states had net energy reductions for cooling/heating over the entire period, but in most other regions energy increases for cooling outweighed energy decreases for heating. The high-ΔT scenario had significantly increased warming, especially in winter, so decreased heating needs led to a cumulative (2003–2025) heating/cooling energy decrease of 0.82 quads. In both scenarios, CO_2 emissions increases from electricity generation outweighed CO_2 emissions decreases from reduced heating needs. The results reveal the intricate energy-economy structure that must be considered in projecting consequences of climate warming for energy, economics, and fossil-fuel carbon emissions.

XOBS

Hadley, S. W., Erickson III, D. J., & Hernandez, J. L. (2006). *Modeling U.S. Energy Use Changes with Global Climate Change, ORNL/TM-2006/524*. Oak Ridge, TN. Retrieved from http://apps.ornl.gov/~pts/prod/pubs/ldoc2494_ornl_degree_day_paper_final.pdf

> Using a general circulation model of Earth climate (PCM-IBIS) to drive an energy use model (DD-NEMS), the energy use changes for each year from 2003-2025 for the nine U.S. Census regions are calculated using five scenarios: 1) a reference with no change in temperatures from the 1970-2003 average, 2) a gradual 1°F rise in temperature by 2025, 3) a gradual 3°F rise by 2025, 4) a climate simulation with low temperature response to CO_2 doubling in the atmosphere, and 5) a climate simulation with a more extreme response.

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Hamlet, A. F., Lee, S.-Y., Mickelson, K. E. B., & Elsner, M. M. (2010). Effects of projected climate change on energy supply and demand in the Pacific Northwest and Washington State. *Climatic Change*, *102*(1-2), 103–128. doi:10.1007/s10584-010-9857-y

> Climate strongly affects energy supply and demand in the Pacific Northwest (PNW) and Washington State (WA). We evaluate potential effects of climate change on the seasonality and annual amount of PNW hydropower production, and on heating and cooling energy demand. Changes in hydropower production are estimated by linking simulated streamflow scenarios produced by a hydrology model to a simulation model of the Columbia River hydro system. Changes in energy demand are assessed using gridded estimates of heating degree days (HDD) and cooling degree days (CDD) which are then combined with population projections to create energy demand indices that respond both to climate, future population, and changes in residential air conditioning market penetration. We find that substantial changes in the amount and seasonality of energy supply and demand in the PNW are likely to occur over the next century in response to warming, precipitation changes, and population growth. By the 2040s hydropower production is projected to increase by 4.7–5.0% in winter, decrease by about 12.1–15.4% in summer, with annual reductions of 2.0–3.4%. Larger decreases of 17.1–20.8% in summer hydropower production are projected for the 2080s. Although the combined effects of population growth and warming are projected to increase heating energy demand overall (22–23% for the 2020s, 35–42% for the 2040s, and 56–74% for the 2080s), warming results in reduced per capita heating demand. Residential cooling energy demand (currently less than one percent of residential demand) increases rapidly (both overall and per capita) to 4.8–9.1% of the total demand by the 2080s due to increasing population, cooling degree days, and air conditioning penetration.

XOBS XREG

Hekkenberg, M., Benders, R. M. J., Moll, H. C., & Schoot Uiterkamp, a. J. M. (2009). Indications for a changing electricity demand pattern: The temperature dependence of electricity demand in the Netherlands. *Energy Policy*, *37*(4), 1542–1551. doi:10.1016/j.enpol.2008.12.030

This study assesses the electricity demand pattern in the relatively temperate climate of the Netherlands (latitude 52°30′N). Daily electricity demand and average temperature during the period from 1970 until 2007 are investigated for possible trends in the temperature dependence of electricity demand. We hypothesize that the increased use of cooling applications has shifted the temperature dependence of electricity demand upwards in summer months. Our results show significant increases in temperature dependence of electricity demand in May, June, September, October and during the summer holidays. During the period studied, temperature dependence in these months has shifted from negative to positive, meaning that a higher temperature now leads to an increased electricity demand in these months, rather than a decreased demand as observed historically. Although electricity demand in countries with moderate summer temperatures such as the Netherlands generally peaks in winter months and shows a minimum in summer months, this trend may signal the development of an additional peak in summer, especially given the expected climatic change. As power generating capacity may be negatively influenced by higher temperatures due to decreasing process cooling possibilities, an increasing electricity demand at higher temperatures may have important consequences for power generation capacity planning and maintenance scheduling.

XOBS XBEH XPRI

Hekkenberg, M., Moll, H. C., & Uiterkamp, a. J. M. S. (2009). Dynamic temperature dependence patterns in future energy demand models in the context of climate change. *Energy*, *34*(11), 1797–1806. doi:10.1016/j.energy.2009.07.037

Energy demand depends on outdoor temperature in a ‘u’ shaped fashion. Various studies have used this temperature dependence to investigate the effects of climate change on energy demand. Such studies contain implicit or explicit assumptions to describe expected socio-economic changes that may affect future energy demand. This paper critically analyzes these implicit or explicit assumptions and their possible effect on the studies’ outcomes. First we analyze the interaction between the socio-economic structure and the temperature dependence pattern (TDP) of energy demand. We find that socio-economic changes may alter the TDP in various ways. Next we investigate how current studies manage these dynamics in socio-economic structure. We find that many studies systematically misrepresent the possible effect of socio-economic changes on the TDP of energy demand. Finally, we assess the consequences of these misrepresentations in an energy demand model based on temperature dependence and climate scenarios. Our model results indicate that expected socio-economic dynamics generally lead to an underestimation of future energy demand in models that misrepresent such dynamics. We conclude that future energy demand models should improve the incorporation of socio-economic dynamics. We propose dynamically modeling several key parameters and using direct meteorological data instead of degree days.

XOBS XPRI XBEH

Henley, A., & Peirson, J. (1998). Residential energy demand and the interaction of price and temperature: British experimental evidence. *Energy Economics*, *20*(2), 157–171. doi:10.1016/S0140-9883(97)00025-X

The responsiveness of heating energy demand to pricing is shown to be dependent on temperature and vice versa. This is investigated empirically using residential electricity demand data obtained under conditions of price variation from a British time-of-use pricing experiment. Results confirm that consumer responses to higher electricity prices are conditional on temperature levels, particularly during the daytime and for households with high overall levels of electricity consumption and previous experience of time-of-use tariffs.

XOBS XPRI

Henley, A., & Peirson, J. (1997). Non-Linearities in Electricity Demand and Temperature: Parametric Versus Non-Parametric Methods. *Oxford Bulletin of Economics and Statistics*, *59*(1), 149–162. doi:10.1111/1468-0084.00054

This paper investigates the relationship between outside air temperature and the residential demand for space heating energy. These non-linearities are investigated empirically using high frequency longitudinal data for a sample of UK households, and both parametric and non-parametric methods for identifying non-linearities are examined. The precise relationship between air temperature and energy demand is the major determinant of day-to-day changes in demand. In order to meet energy demand and for energy spot markets to operate efficiently, electricity suppliers require reliable forecasts of demand. These require that the relationship between temperature and energy demand be specified appropriately.

XPOP

Henrie, C. J., & Plane, D. A. (2006). Decentralization of the Nation's Main Street: New Coastal- Proximity-Based Portrayals of Population Distribution in the United States, 1950–2000. *The Professional Geographer*, *58*(4), 448–459.

This article documents the emergence of a bicoastal population distribution in the United States, specifically into megalopolises on both the Atlantic and Pacific coasts. Using historical census data and GIS technology, a number of novel ways to graphically portray and examine this population redistribution phenomenon are presented.

XOBS XBEH

Hitchings, R. (2011). Researching air-conditioning addiction and ways of puncturing practice: professional office workers and the decision to go outside. *Environment and Planning A*, *43*(12), 2838–2856. doi:10.1068/a43574

The author combines theories of social practice with a program of serial interviews with a sample of city professionals in order to identify ways of disrupting otherwise habitual indoor existence and discouraging people from becoming increasingly reliant on ambient conditions that are environmentally costly to supply. One broad conclusion is that studies examining how places and practices produce decisions play a part in fostering positive social futures.

XPOP

Hunter, L. M. (2005). Migration and Environmental Hazards. *Population and environment*, *26*(4), 273–302. doi:10.1007/s11111-005-3343-x

> This paper offers a review of research examining the association between migration and environmental hazards. Using examples from both developed and developing regional contexts, the overview demonstrates that the association between migration and environmental hazards varies by setting, hazard types, and household characteristics. In many cases, however, results demonstrate that environmental factors play a role in shaping migration decisions, particularly among those most vulnerable. Research also suggests that risk perception acts as a mediating factor. Classic migration theory is reviewed to offer a foundation for examination of these associations.

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International Energy Agency. (2012). *World Energy Outlook 2012*.

XOBS XREG

Isaac, M., & Van Vuuren, D. P. (2009). Modeling global residential sector energy demand for heating and air conditioning in the context of climate change. *Energy Policy*, *37*(2), 507–521. doi:http://dx.doi.org/10.1016/j.enpol.2008.09.051

> The potential development of energy use for future residential heating and air conditioning in the context of climate change is assessed. In a reference scenario, global energy demand for heating is projected to increase until 2030 and then stabilize. In contrast, energy demand for air conditioning is projected to increase rapidly over the whole 2000–2100 period, mostly driven by income growth. The associated CO_2 emissions for both heating and cooling increase from 0.8Gt C in 2000 to 2.2Gt C in 2100, i.e. about 12% of total CO_2 emissions from energy use (the strongest increase occurs in Asia). The net effect of climate change on global energy use and emissions is relatively small as decreases in heating are compensated for by increases in cooling. However, impacts on heating and cooling individually are considerable in this scenario, with heating energy demand decreased by 34% worldwide by 2100 as a result of climate change, and air-conditioning energy demand increased by 72%. At the regional scale considerable impacts can be seen, particularly in South Asia, where energy demand for residential air conditioning could increase by around 50% due to climate change, compared with the situation without climate change.

XEQP

Jaboyedoff, P., Roulet, C.-A., Dorer, V., Weber, A., & Pfeiffer, A. (2004). Energy in air-handling units—results of the AIRLESS European Project. *Energy and Buildings*, *36*(4), 391–399. doi:http://dx.doi.org/10.1016/j.enbuild.2004.01.047

> This paper addresses the energy use in air-handling units and proposes several energy-efficient ways to provide good indoor air and even efficient indoor environment conditioning. Cooling energy may be important in office buildings, even in temperate climate. An efficient and cheap cooling strategy is to combine a mechanical ventilation system designed for the minimum hygienic airflow rate with night passive cooling using natural ventilation.

XOBS XEQP XREG

Jenkins, D., Liu, Y., & Peacock, A. D. (2008). Climatic and internal factors affecting future UK office heating and cooling energy consumptions. *Energy and Buildings*, *40*(5), 874–881. doi:http://dx.doi.org/10.1016/j.enbuild.2007.06.006

> This study aims to quantify how changes in the UK climate in the coming decades will have a direct effect on heating and cooling energy use in future office environments (i.e. by the year 2030) and also seeks to inform future choices for supplying energy to office buildings – in particular, microgeneration options. It confirms the importance of dealing with demand-side changes before assessing the supply-side opportunities, with buildings having very different heating and cooling needs post-refurbishment. The study also highlights the importance, and possibilities, of adapting to future climates, and the benefits of promoting heating-dominated buildings instead of cooling-dominated.

XOBS XPOP

Jiang, L., & Hardee, K. (2010). How do Recent Population Trends Matter to Climate Change? *Population Research and Policy Review*, *30*(2), 287–312. doi:10.1007/s11113-010-9189-7

> This paper explores how global population dynamics affect carbon emissions and climate systems, how recent demographic trends matter to worldwide efforts to adapt to climate change, and how population policies could make differences for climate change mitigation and adaptation.

XOBS XBEH XEQP

Kempton, W., Feuermann, D., & McGarity, A. E. (1992). "I always turn it on super": user decisions about when and how to operate room air conditions. *Energy and Buildings*, *18*, 177–191.

> Room air-conditioner operation was studied in order to understand how energy consumption and peak power demand are determined by user needs, concepts, and behavior. In a multi-family building in New Jersey, thirteen room air conditioners were instrumented in eight apartments, and the residents were interviewed about their cooling needs, decisions about when to turn on their air-conditioning, and their conceptions and operation of the units.

XOBS

Lam, J. C. (1998). Climatic and economic influences on residential electricity consumption. *Energy Conversion and Management*, *39*(7), 623–629. Retrieved from http://www.sciencedirect.com/science/article/pii/S0196890497100085.

> We have performed regression and correlation analyses to investigate the relationships between residential electricity consumption and economic variables and climatic factors for Hong Kong. Economic and energy data for the 23-year period from 1971 to 1993 have been gathered and analyzed. It has been found that both the seasonal and the yearly electricity use in the residential sector can be estimated based on the household income, household size, electricity price and cooling degree-days.

XOBS

Le Comte, D. M., & Warren, H. E. (1981). Modeling the Impact of Summer Temperatures on National Electricity Consumptions. *Journal of Applied Meteorology*, 20.

National population-weighted weekly degree day totals, which have been used to model and assess temperature-related natural gas consumption, are compared with summertime electricity consumption. A very close relationship between national cooling degree days and electricity consumption is found. A multiple regression equation depicting the relationship is developed. This model can be used to assess the impact of current weather anomalies and projected weather or climate changes on electricity use, as well as the impact of various national conservation measures, directives, or laws on temperature-related electricity use.

XOBS XREG

Lebassi, B., González, J. E., Fabris, D., & Bornstein, R. (2010). Impacts of Climate Change in Degree Days and Energy Demand in Coastal California. *Journal of Solar Energy Engineering*, *132*(3), 031005. doi:10.1115/1.4001564

An analysis of 1970–2005 observed summer daily maximum and minimum temperatures in two California air basins showed concurrent daytime coastal cooling and inland warming. To study the impacts of these results on energy consumption, summer cooling degree day (CDD) and winter heating degree day (HDD) trends were analyzed via these temperatures. An analysis of the CDD and HDD data has been undertaken for California, in general, and the San Francisco Bay Area and South Coast Air Basin, in particular, as the source of data for an analysis of energy-demand trends. Regional climate fluctuations have considerable effects on surface temperatures, which in turn affect CDD and HDD values. An asymmetric increase in summer CDD values between coastal and inland regions of California was found during the last 35 years, while winter HDD values showed decreases in most of California.

XOBS XPRI XBEH

Lee, C.-C., & Chiu, Y.-B. (2011). Electricity demand elasticities and temperature: Evidence from panel smooth transition regression with instrumental variable approach. *Energy Economics*, *33*(5), 896–902. doi:10.1016/j.eneco.2011.05.009

This study applies a non-linear model, i.e. the recently developed panel smooth transition regression (PSTR) model, and takes into account the potential endogeneity biases to investigate the demand function of electricity for 24 OECD countries from the period 1978–2004. Our empirical results demonstrate that there is a strongly non-linear link among electricity consumption, real income, electricity price, and temperature, a result that is new to the literature. As real income rises, electricity consumption rapidly increases first, and after the level of real income exceeds approximately US$2500, its increasing rate turns slow down. An increase in electricity price has a negative or no influence on electricity consumption. Evidence of a U-shaped relationship between electricity consumption and temperature is supported, and the threshold value of temperature is approximately 53 °F, which is endogenously determined. Furthermore, the estimated elasticities of time dynamic indicate that electricity demand is income inelastic, price inelastic, and temperature inelastic. As time goes on, the absolute elasticities of electricity demand gradually decrease with respect to real GDP and electricity price, whereas they gradually increase with respect to temperature, suggesting that the impact of temperature on electricity demand is becoming more important in recent years.

XOBS XPOP XREG

Leichenko, R. M. (2001). Growth and Change in U.S. Cities and Suburbs. *Growth and Change*, *32*(Summer 2001), 326–354.

> This paper examines the determinants of growth in cities and suburbs during the 1970s, the 1980s, and the 1990s. The modeling approach adopted in the study allows for simultaneity between population and employment, and between cities and suburbs, while also taking into account a range of other explanatory factors. Results indicate that population and employment growth in cities tend to be jointly determined, but that growth of employment in the suburbs tends to drive growth of suburban population. Results also suggest that suburban and city growth are interrelated, but that the nature of these interrelationships varies over time: suburban growth promoted city growth during the 1970s and 1980s, while city and suburban growth were jointly determined during the 1990s.

XOBS XEQP

Li, D. H. W., Yang, L., & Lam, J. C. (2012). Impact of climate change on energy use in the built environment in different climate zones – A review. *Energy*, *42*(1), 103–112. doi:10.1016/j.energy.2012.03.044

> Studies on the impact of climate change on energy use in buildings in the different parts of the world were reviewed. Potential mitigation and adaptation measures were discussed and further research work suggested. In severe cold climates reduction in heating requirement would outweigh the modest increase in summer cooling. In the hot summer and cold winter climate zones where both winter heating and summer cooling requirements are important, the magnitude of reduction in heating and the magnitude of increase in cooling could be comparable. The most significant impact on energy use in the built environment would occur in the hot summer and warm winter climates where building energy use is dominated by cooling requirement. Raising the summer set point temperature and reducing the lighting load density would have great energy savings and hence mitigation potential. Space heating is provided largely by oil- or gas-fired boiler plants whereas space cooling mainly relies on electricity. This would result in a shift towards more electrical demand and could have important implications for the nationwide energy and environmental policy for the built environment.

XOBS XEQP

Lin, Z., & Deng, S. (2004). A study on the characteristics of nighttime bedroom cooling load in tropics and subtropics. *Building and Environment*, *39*(9), 1101–1114. doi:http://dx.doi.org/10.1016/j.buildenv.2004.01.035

> This paper reports on a simulation study on the characteristics of nighttime bedroom cooling load in tropics and subtropics, using a building energy simulation program. The weather conditions of and the typical arrangements of high-rise residential blocks in Hong Kong are used in the simulation study. The simulation results on the cooling load characteristics in bedrooms under three different operating modes of room air conditioners (RACs) at the summer design day, the breakdown of the total cooling load in a bedroom at nighttime operating mode (NOM), indoor air temperature and mean radiant temperature variation at NOM, and the effects of indoor design air temperature on the cooling load characteristics at NOM are presented. The differences in the cooling load characteristics among three different operating modes and the issues related to the sizing of RACs used in bedrooms are discussed.

XOBS

Liu, X., & Sweeney, J. (2012). The impacts of climate change on domestic natural gas consumption in the Greater Dublin Region. *International Journal of Climate Change Strategies and Management*, *4*(2), 161–178. doi:10.1108/17568691211223141.

> This paper aims to investigate the relationship between domestic natural gas consumption and climate change in the Greater Dublin Region. Based on historical climate and natural gas use data, a linear regression model was derived to estimate the impact of future climate change on natural gas consumption under different climate scenarios. Generally, under controlled socioeconomic development, the climate scenarios by Hadley model and the Ensemble GCMs are likely to decrease future natural gas consumption per capita and related CO2 emissions compared to present. These results indicate that climate change has become as one of the most important factors affecting the energy system. This study contributes understanding of the long-term impact of climate change on regional domestic natural gas use. It provides the national and local authorities a methodology to anticipate the potential impacts on domestic energy use and enable urban areas to maximize any benefits and minimize any losses from climate change.

XOBS XEQP

Loveland, J. E., & Brown, G. Z. (1989). *Impacts of Climate Change on the Energy Performance of Buildings in the United States.*

> This study uses computer simulation techniques to assess the impacts of climate change on building energy demand. This analysis allows for the characterization of the potential for reducing the energy use of buildings in a quantitative manner and therefore improving building design. Six cities and five building types representing a range of climates and building occupancies were modeled. Three design strategies for improving energy performance under warmed conditions are compared to a basecase. The study concludes that annual cooling loads will increase at a much greater rate than heating loads will decrease; The timing, magnitude and duration of short term changes, peaks, is as large a concern as the sheer magnitude of the large annual changes in demand due to Global Warming; new methods of resource acquisition will have to be implemented to respond to the new energy resource demands; and a new set of incremental measures, conservation targets, will have to be developed to support new resources. The results of the study indicate that research and demonstration of regional building unit area weighted, zero energy growth, energy demand targets should be developed. These regional energy conservation targets should emphasize the saving of lost opportunity resources in the design of the most permanent of the building systems, the building's exterior skin geometry. assembly and interiors. The study indicates that the clearest specific target for reducing energy use under Global Warming is the design of windows. The research, design. and demonstration of windows that act as an integrated lighting system with the electric lighting; admitting daylight, view, and cooling ventilation without admitting sunlight; should be a major thrust for research and development of the 1990s.

XOBS

Mack, N., & Broder, J. M. (2005). *Georgia Annual report of accomplishments FY 2004*. Retrieved from http://www.reeis.usda.gov/web/areera/Reports/2004/Combined.GA.pdf

XOBS

Mansur, E. T., Mendelsohn, R., & Morrison, W. (2008). Climate change adaptation: A study of fuel choice and consumption in the US energy sector. *Journal of Environmental Economics and Management*, *55*(2), 175–193. doi:http://dx.doi.org/10.1016/j.jeem.2007.10.001

> Using cross-sectional data, this paper estimates a national energy model of fuel choice by both households and firms. Consumers in warmer locations rely relatively more heavily on electricity rather than natural gas, oil, and other fuels. They also use more energy. Climate change will likely increase electricity consumption on cooling but reduce the use of other fuels for heating. On net, American energy expenditures will likely increase, resulting in welfare damages that increase as temperatures rise. For example, if the US warms by 5°C by 2100, annual welfare losses of $57 billion are predicted.

XOBS

Mansur, E. T., Mendelsohn, R., & Morrison, W. (2005). A Discrete-Continuous Choice Model of Climate Change Impacts on Energy.

> This paper estimates a multinomial discrete-continuous fuel choice model of both households and firms in order to determine the sensitivity of national energy demand to climate change. We find that consumers switch from natural gas, oil, and other fuels to electricity as climate warms and that overall energy demand—especially electricity demand—increases. The model implies that warming will increase American energy expenditures, resulting in welfare damages that increase as temperatures rise. Increases in electricity expenditures for cooling are partially offset by reductions in expenditures on other fuels for heating. Given a five degree Celsius increase in temperature by 2100, we predict an annual welfare loss of $40 billion, borne primarily by residential customers.

XOBS XPOP XREG

Maxwell, J. T., & Soulé, P. T. (2011). Drought and Other Driving Forces behind Population Change in Six Rural Counties in the United States. *Southeastern Geographer*, *51*(Deming 1996), 133–149.

> Population change in six rural counties of three different regions in the United States were examined along with the potential influence of drought as measured by the Cook et al. (2004) study. The driving forces behind population change in each case study county were determined through correlation and regression analysis. The traditional variables accounted for the majority of population change. While drought explained a small percentage of the variance in population change, it was significant in three out of the six counties and in each region examined. Spatially, with the exception of the climatic variables, counties within the same region tended to have similar driving forces for population change.

XOBS XPOP XREG

McLeman, R. (2009). Impacts of population change on vulnerability and the capacity to adapt to climate change and variability: a typology based on lessons from “a hard country”. *Population and Environment*, *31*(5), 286–316. doi:10.1007/s11111-009-0087-z

> This article describes and analyzes the impacts of population and demographic change on the vulnerability of communities to climate change and variability. It begins with a review of existing literature on the effects of population change on anthropogenic greenhouse gas emissions, the exposure of settlements to climate risks, and on the capacity to adapt to climate change. The article explores the relationship between population change and adaptive capacity through detailed examination of empirical findings from a study of small communities in eastern Ontario, Canada currently experiencing a combination of changes in local climatic conditions and rapid demographic change caused by in-migration of urban retirees and out-migration of young, educated people. The case study and literature review are used to create a general typology of the relationship between population change and vulnerability that may be used as a framework for future research in this field.

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McLeman, R., Mayo, D., Strebeck, E., & Smit, B. (2007). Drought adaptation in rural eastern Oklahoma in the 1930s: lessons for climate change adaptation research. *Mitigation and Adaptation Strategies for Global Change*, *13*(4), 379–400. doi:10.1007/s11027-007-9118-1

> In the mid-1930s, eastern Oklahoma, USA, suffered an unusually harsh mixture of droughts and extreme rainfall events that led to widespread crop failure over several years. These climatic conditions coincided with low commodity prices, agricultural restructuring and general economic collapse, creating tremendous hardship in rural and agriculturally dependent areas. Using a previously developed typology of agricultural adaptation, this paper reports empirical research conducted to identify the ways by which the rural population of Sequoyah County adapted to such conditions. Particular attention is given to categorizing the scale at which adaptation occurred, the actors involved and the constraints to implementation. The findings identify successes and opportunities missed by public policy makers, and suggest possible entry points for developing adaptation strategies for current and future, analogous situations that may arise as a result of climate change.

XOBS XREG

Mendelsohn, R. (n.d.). *Appendix XI The Impact of Climate Change on Energy Expenditures in California.*

In this appendix, we use a national cross-sectional analysis and detailed data from California to examine the sensitivity of energy expenditures to climate change in the state. The analysis begins with a logit regression that explains the probability that a building will be cooled. Long- and short-run cross-sectional approaches are then explored to estimate the sensitivity of energy expenditures and buildings to changes in climate. The national analysis suggests that energy expenditures for both residential and commercial property have a U-shaped relationship with respect to temperature. This empirical relationship is then used to analyze climate change in individual counties in California. The results suggest that warming will increase average energy expenditures in residential and commercial buildings and cause damages, but the effects across the state are not uniform. Northern and mountainous counties are more likely to reduce energy expenditures (a benefit) and central valley and southern counties are more likely to increase energy expenditures (a damage). With mild climate scenarios, statewide annual projected damages are in the range of $1 billion to $9 billion but with more severe climate scenarios, damages can climb to between $8 billion and $18 billion by 2100.

XOBS XPRI

Mideksa, T. K., & Kallbekken, S. (2010). The impact of climate change on the electricity market: A review. *Energy Policy*, *38*(7), 3579–3585. doi:10.1016/j.enpol.2010.02.035

Climate change will impact electricity markets through both electricity demand and supply. This paper reviews the research on this topic. Whereas there is much that remains unknown or uncertain, research over the last few years has significantly advanced our knowledge. In general, higher temperatures are expected to raise electricity demand for cooling, decrease demand for heating, and to reduce electricity production from thermal power plants. The effect of climate change on the supply of electricity from non-thermal sources shows great geographical variability due to differences in expected changes to temperature and precipitation. Whereas the research frontier has advanced significantly in the last few years, there still remains a significant need for more research in order to better understand the effects of climate change on the electricity market. Four significant gaps in the current research are regional studies of demand side impacts for Africa, Asia, the Caribbean and Latin America, the effects of extreme weather events on electricity generation, transmission and demand, changes to the adoption rate of air conditioning, and finally, our understanding of the sensitivity of thermal power supply to changes in air and water temperatures.

XOBS XBEH XPOP XREG

Miller, N., Hayhoe, K., Jin, J., & Auffhammer, M. (2007). Climate, extreme heat, and electricity demand in California. Retrieved from http://works.bepress.com/cgi/viewcontent.cgi?article=1014&context=auffhammer

Climate projections from three atmosphere-ocean climate models with a range of low to mid-high temperature sensitivity forced by the Intergovernmental Panel for Climate Change SRES higher, middle, and lower emission scenarios indicate that, over the 21st century, extreme heat events for major cities in heavily air-conditioned California will increase rapidly. These increases in temperature extremes are projected to exceed the rate of increase in mean temperature, along with increased variance. Extreme heat is defined here as the 90 percent exceedance probability (T90) of the local warmest summer days under the current climate. The number of extreme heat days in Los Angeles, where T90 is currently 95°F (32°C), may increase from 12 days to as many as 96 days per year by 2100, implying current-day heat wave conditions may last for the entire summer, with earlier onset. Overall, projected increases in extreme heat under the higher A1fi emission scenario by 2070-2099 tend to be 20-30 percent higher than those projected under the lower B1 emission scenario, ranging from approximately double the historical number of days for inland California cities (e.g. Sacramento and Fresno), up to four times for previously temperate coastal cities (e.g. Los Angeles, San Diego). These findings, combined with observed relationships between high temperature and electricity demand for air-conditioned regions, suggest potential shortfalls in transmission and supply during T90 peak electricity demand periods. When the projected extreme heat and peak demand for electricity are mapped onto current availability, maintaining technology and population constant only for demand side calculations, we find the potential for electricity deficits as high as 17 percent. Similar increases in extreme heat days are suggested for other locations across the U.S. southwest, as well as for developing nations with rapidly increasing electricity demands. Electricity response to recent extreme heat events, such as the July 2006 heat wave in California, suggests that peak electricity demand will challenge current supply, as well as future planned supply capacities when population and income growth are taken into account.

XOBS

Mirasgedis, S., Sarafidis, Y., Georgopoulou, E., Lalas, D., Moschovits, M., Karagiannis, F., & Papakonstantinou, D. (2006). Models for mid-term electricity demand forecasting incorporating weather influences. *Energy*, *31*(2-3), 208–227. doi:10.1016/j.energy.2005.02.016

Electricity demand forecasting is becoming an essential tool for energy management, maintenance scheduling and investment decisions in the future liberalized energy markets and fluctuating fuel prices. To address these needs, appropriate forecasting tools for the electricity demand in Greece have been developed and tested. Electricity demand depends on economic variables and national circumstances as well as on climatic conditions. Following the analysis of the time series of electricity demand in the past decade, two statistical models have been developed, one providing daily and the other monthly demand predictions, to estimate medium term demand up to 12 months ahead, utilizing primitive (relative humidity) and derived (heating and cooling degree-days) meteorological parameters. Autoregressive structures were incorporated in both models, aiming at reducing serial correlation, which appears to bias the estimated effects of meteorological parameters on electricity demand. Both modeling approaches show a high predictive value with adjusted R2 above 96%. Their advantages and disadvantages are discussed in this paper. The effect of the climatic conditions on the electricity demand is then further investigated via predictions under four different scenarios for the weather conditions of the coming year, which include both normal and recently observed extreme behavior.

XPOP
Moore, E. J., & Smith, J. W. (1995). Climatic change and migration from Oceania: Implications for Australia, New Zealand and the United States of America. *Population and Environment*, *17*(2), 105–122. doi:10.1007/BF02208383

This paper attempts to assess possible migration flows which may occur, in response to climatic shifts over the next thirty years, from small island states in the south-west Pacific Ocean region to the United States, Australia and New Zealand. It is argued that the small island states appear vulnerable to climatic change, with low coral atolls being most at risk. Adverse impacts of climatic change will be one extra pressure on small island states, many of which are already struggling to cope with sustainable management of their natural resources and with the demands of their rapidly growing populations for education, housing and employment. The migration strategy is likely to entail significant medium-term health, psychological, and social costs for some Pacific island migrants as they try to move or cope with life in western industrialized societies.

XOBS XBEH
Moral-Carcedo, J., & Vicéns-Otero, J. (2005). Modelling the non-linear response of Spanish electricity demand to temperature variations. *Energy Economics*, *27*(3), 477–494. doi:10.1016/j.eneco.2005.01.003

The demand for electricity is a key variable because its links to economic activity and development; however, the electricity consumption also depends on other non-economic variables, notably the weather. The aim of this study is to analyze the effect of temperatures on the variability of the Spanish daily electricity demand, and especially to characterize the non-linearity of the response of demand to variations in temperature. In this article, we explore the ability of Smooth Transition (STR), Threshold Regression (TR), and Switching Regressions (SR) models, to handle both aspects. As we conclude, the use of LSTR approach offers two main advantages. First, it captures adequately the smooth response of electricity demand to temperature variations in intermediate ranges of temperatures. Second, it provides a method to analyze the validity of temperature thresholds used to build the "cooling degree days" (CDD) and "heating degree days" (HDD) variables traditionally employed in the literature.

XOBS XEQP

Morris, M. (1999). *The Impact of Temperature Trends on Short-Term Energy Demand* (pp. 1–12).

The past few years have witnessed unusually warm weather, as evidenced by both mild winters and hot summers. The most recent winter was the second warmest on record, and the summer of 1998 set new U.S. and worldwide temperature records. Climatologists have concluded that the recent spate of unusually warm weather is part of a warming trend that dates to 1965, and that this trend is likely to continue. The trend has also exhibited distinct seasonal and regional variations: winters have experienced a greater warming trend than other seasons, and the West has been more prone to warming than the rest of the Lower-48 states. The analysis shows that the 30-year norms--the basis of weather-related energy demand projections--do not reflect the warming trend or its regional and seasonal patterns. Weather premises based on climate change result in lower energy demand projections. The concentration of the warming trend during the winter season results in a reduction of projected space-heating requirements exceeding increases in summer cooling demand that also result from the same trend.

XOBS XPRI

Morrison, W., & Mendelsohn, R. (1998). *The Impacts of Climate Change on Energy an aggregate expenditure model for the US*.

This paper develops a theoretical model to measure the climate change impacts to the energy sector. Welfare effects are approximately equal to the resulting change in expenditures on energy and buildings. Using micro data on individuals and firms across the United States, energy expenditures are regressed on climate and other control variables to estimate both short-run and long-run climate response functions. The analysis suggests that energy expenditures have a quadratic U-shaped relationship with respect to temperature. Future warming of 2C is predicted to cause annual damages of about $6 billion but increases of 5C would increase damages to almost $30 billion.

XBEH XPOP

Nelson, D. R. (2010). Climate change: understanding anthropogenic contributions and responses. *Population and Environment*, *31*(5), 283–285. doi:10.1007/s11111-010-0109-x

> The author's guest editorial introduces a compendium of articles by other articles connecting the subjects of climate change, population responses to same, and the connection to human activity and carbon emissions. Other articles include one that introduces vulnerability as a way of evaluating adaptation strategies and another addressing the need for improved governance structures.

XOBS XBEH XEQP XREG

Nordman, B., & Meier, A. (1988). Outdoor-Indoor Temperature Relationships. *ACEEE 1988 Summer Study on Energy Efficiency in Buildings*.

> The authors detect unusual patterns in indoor/outdoor temperature data from Pacific Northwest houses and perform computer simulations of similar houses to generate synthetic indoor temperatures for comparison. The simulations demonstrate that the observed indoor and outdoor temperature patterns can be explained by thermostat setbacks and floating; the results improve understanding of thermostat behavior and permit more realistic estimates of heating energy use for houses operated with thermostat setbacks.

XOBS XREG

Oak Ridge National Laboratory. (2012). Climate Change and Infrastructure, Urban Systems, and Vulnerabilities. Oak Ridge, Tennessee. Retrieved from www.esd.ornl.gov/eess/Infrastructure.pdf

> This report arrives at a number of "assessment findings," each associated with an evaluation of the level of consensus on that issue within the expert community and the volume of evidence available to support that judgment.

XOBS XREG

Oak Ridge National Laboratory. (2012). Climate Change and Energy Supply and Use. Oak Ridge, Tennessee. Retrieved from www.esd.ornl.gov/eess/Infrastructure.pdf

> This report arrives at a number of "assessment findings," each associated with an evaluation of the level of consensus on that issue within the expert community and the volume of evidence available to support that judgment.

XOBS XPRI

Olonscheck, M., Holsten, A., & Kropp, J. P. (2011). Heating and cooling energy demand and related emissions of the German residential building stock under climate change. *Energy Policy*, *39*(9), 4795–4806. doi:10.1016/j.enpol.2011.06.041

The housing sector is a major consumer of energy. Studies on the future energy demand under climate change which also take into account future changes of the building stock, renovation measures and heating systems are still lacking. We provide the first analysis of the combined effect of these four influencing factors on the future energy demand for room conditioning of residential buildings and resulting greenhouse gas (GHG) emissions in Germany until 2060. We show that the heating energy demand will decrease substantially in the future. This shift will mainly depend on the number of renovated buildings and climate change scenarios and only slightly on demographic changes. The future cooling energy demand will remain low in the future unless the amount of air conditioners strongly increases. As a strong change in the German energy mix is not expected, the future GHG emissions caused by heating will mainly depend on the energy demand for future heating.

XBEH XEQP
Peffer, T., Pritoni, M., Meier, A., Aragon, C., & Perry, D. (2011). How people use thermostats in homes: A review. *Building and Environment*, *46*(12), 2529–2541. doi:10.1016/j.buildenv.2011.06.002

This review covers the evolution in technologies of residential thermostats, discussing studies of how people currently use thermostats, finding that nearly half do not use the programming features. The review covers the complications associated with using a thermostat. Finally, the authors suggest research needed to design (and especially test with users) thermostats that can provide more comfortable and economical indoor environments.

XPRI
Peirson, J., & Henley, A. (1994). Electricity load and temperature Issues in dynamic specification. *Energy Economics*, *16*(4), 235–243.

This paper considers the dynamic specification of the relationship between electricity load and air temperature. It is shown that this relationship has an important dynamic component and that ignoring this appears to bias the estimated effects of temperature on load. It is also shown that forms of autoregressive specification may give a good explanation of present load even if there are no dynamics in the causal relation. The assumptions underlying effective temperature and its empirical validity are investigated. Dynamic specification of the temperature response is shown to be conditional on the time of day, which brings into question the use of the effective temperature concept.

XOBS XPRI
Petrick, S., Rehdanz, K., & Tol, R. S. J. (2010). The Impact of Temperature Changes on Residential Energy Consumption Energy Consumption.

To investigate the link between rising global temperature and global energy use, we estimate an energy demand model that is driven by temperature changes, prices and income. The estimation is based on an unbalanced panel of 157 countries over three decades. We limit the analysis to the residential sector and distinguish four different fuel types (oil, natural gas, coal and electricity). Compared to previous papers, we have a better geographical coverage and consider non-linarites in the impact of temperature on energy demand as well as temperature-income interactions. We find that oil, gas and electricity use are driven by a non-linear heating effect: Energy use not only decreases with rising temperatures due to a reduced demand for energy for heating purposes, but the speed of that decrease declines with rising temperature levels. Furthermore we find evidence that the temperature elasticity of energy use is affected by the level of temperature as well as the level of income.

XPRI XREG

Pilli-Sihvola, K., Aatola, P., Ollikainen, M., & Tuomenvirta, H. (2010). Climate change and electricity consumption—Witnessing increasing or decreasing use and costs? *Energy Policy*, *38*(5), 2409–2419. doi:10.1016/j.enpol.2009.12.033

Climate change affects the need for heating and cooling. This paper examines the impact of gradually warming climate on the need for heating and cooling with an econometric multivariate regression model for five countries in Europe along the south–north line. The predicted changes in electricity demand are then used to analyze how climate change impacts the cost of electricity use, including carbon costs. Our main findings are, that in Central and North Europe, the decrease in heating due to climate warming, dominates and thus costs will decrease for both users of electricity and in carbon markets. In Southern Europe climate warming, and the consequential increase in cooling and electricity demand, overcomes the decreased need for heating. Therefore costs also increase. The main contributors are the role of electricity in heating and cooling, and the climatic zone.

XOBS XEQP

Pyke, C. R., McMahon, S., Larsen, L., Rajkovich, N. B., & Rohloff, A. (2012). Development and analysis of Climate Sensitivity and Climate Adaptation opportunities indices for buildings. *Building and Environment*, *55*(0), 141–149. doi:http://dx.doi.org/10.1016/j.buildenv.2012.02.020

In this study, opportunities to assess Climate Sensitivity and adaptive opportunities associated with green building practice are considered. The authors developed a pair of complementary indicators called the Climate Sensitivity Index (CSI) and Climate Adaptation Opportunity Index (CAOI) and applied them to evaluate individual strategies (“credits”) within the Leadership in Energy and Environmental Design (LEED™) for New Construction rating system. The indices provide two complementary scores for each strategy. The CSI reflects potential sensitivity to changing conditions (i.e., risks to performance outcomes), and the CAOI indicates potential adaptive opportunities (i.e., plausible strategies to adapt to changing conditions). The indices are then applied to retrospectively examine the prevalence of potentially sensitive and adaptive practices among a global set of 2440 LEED-certified projects. Adaptive opportunities were more prevalent than sensitivities in the LEED-NC rating system. The CSI and CAOI indices illustrate how information can be derived by interpreting patterns of LEED credit achievement.

XOBS XREG

Reid, C. E., O'Neill, M. S., Gronlund, C. J., Brines, S. J., Brown, D. G., Diez-Roux, A. V, & Schwartz, J. (2009). Mapping community determinants of heat vulnerability. *Environmental health perspectives*, *117*(11), 1730–6. doi:10.1289/ehp.0900683

> The authors situate vulnerability to heat in geographic space and identify potential areas for intervention and further research. Ten vulnerability factors for heat-related morbidity/mortality in the United States were mapped: six demographic characteristics and two household air conditioning variables from the U.S. Census Bureau, vegetation cover from satellite images, and diabetes prevalence from a national survey. A factor analysis of these ten variables was performed, assigning values of increasing vulnerability for the four resulting factors to each of 39,794 census tracts; these four factor scores were to obtain a cumulative heat vulnerability index value. The factors of social/environmental vulnerability, social isolation, air conditioning prevalence, and proportion of elderly/diabetes explained >75% of the total variance in the original ten vulnerability variables. Substantial spatial variability of heat vulnerability was found nationally, with generally higher vulnerability in the Northeast and Pacific Coast and the lowest in the Southeast. In urban areas, inner cities showed the highest vulnerability to heat. These methods provide a template for making local and regional heat vulnerability maps. After validation using health outcome data, interventions can be targeted at the most vulnerable populations.

XOBS XBEH XEQP

Roaf, S., Crichton, D., & Nicol, F. (2005). *Adapting buildings and cities for climate change*. Architectural Press Oxford.

> From back cover: "[This book] is an essential reference work for all involved in the design and management of buildings and cities in a rapidly changing climate, at a time when we can no longer rely on cheap fossil fuel energy. Unless building design is improved, climatic events such as storms, floods and heat waves will increasingly damage buildings and cities, and the economies and societies that rely on them...This fully revised second edition includes three new chapters which present evidence of escalating rates of environmental change. They examine possible mitigation and adaptation responses that begin to deal with the resulting challenge of how to protect our buildings, cities and lifestyles against the risks of extreme weather, as fuel prices and energy insecurity rise."

XOBS

Rosenthal, D. H., Gruenspecht, H. K., & Moran, E. (1995). Effects of global warming on energy use for space heating and cooling in the United States. *Energy Journal*, *16*(2), 77–96.

This study uses a three-step approach to estimate the impact of global warming on U.S. energy expenditures for space heating and cooling in residential and commercial buildings. First, average results from six different global circulation models are used to estimate the change in heating and cooling degree days in five U.S. climate zones associated with a 1º centigrade (C) global warming. Second, the change in degree days is mapped into a corresponding change in U.S. energy use for space conditioning, taking account of differences in population and baseline space conditioning intensity levels across regions, under the assumption that desired indoor temperature is unaffected by climate change. Finally, we estimate the associated change in energy expenditures. We find that a global warming of 1ºC would reduce projected U. S. energy expenditures in 2010 by $ 5.5 billion (1991 dollars). This contrasts with earlier studies which have suggested modest global warming would increase U.S. expenditures on space conditioning energy.

XOBS

Ruth, M., & Lin, A.-C. (2006). Regional energy demand and adaptations to climate change: Methodology and application to the state of Maryland, USA. *Energy Policy*, *34*(17), 2820–2833. doi:10.1016/j.enpol.2005.04.016

This paper explores potential impacts of climate change on natural gas, electricity and heating oil use by the residential and commercial sectors in the state of Maryland, USA. Time series analysis is used to quantify historical temperature–energy demand relationships. A dynamic computer model uses those relationships to simulate future energy demand under a range of energy prices, temperatures and other drivers. The results indicate that climate exerts a comparably small signal on future energy demand, but that the combined climate and non-climate-induced changes in energy demand may pose significant challenges to policy and investment decisions in the state.

XOBS XBEH XEQP XREG

Sailor, D., & Pavlova, A. (2003). Air conditioning market saturation and long-term response of residential cooling energy demand to climate change. *Energy*, *28*(9), 941–951. doi:10.1016/S0360-5442(03)00033-1

Existing state-level models relating climate parameters to residential electricity consumption indicate a nominal sensitivity of 2–4% for each degree Celsius increase in ambient temperatures. Long-term climate change will also impact electricity consumption through corresponding increases in the market saturation of air conditioning. In this paper we use air conditioning market saturation data for 39 US cities to develop a generalized functional relationship between market saturation and cooling degree days. The slope of this saturation curve is particularly high for cities that currently have low to moderate saturation. As a result, the total response of per capita electricity consumption to long-term warming may be much higher than previously thought. A detailed analysis of 12 cities in four states shows that for some cities changes in market saturation may be two to three times more important than the role of weather sensitivity of current loads. While actual behavioral response to climate change will be more complicated than that captured in our model of market saturation, this approach provides a new perspective on the sensitivity of space conditioning electricity consumption in the US to climate change.

XOBS XREG

Sailor, D. J. (2001). Relating residential and commercial sector electricity loads to climate—evaluating state level sensitivities and vulnerabilities. *Energy*, *26*(7), 645–657. doi:10.1016/S0360-5442(01)00023-8

> A methodology for relating climate parameters to electricity consumption at regional scales has been applied to eight states resulting in predictive models of per capita residential and commercial electricity consumption. In isolating residential and commercial consumption these models allow for detailed analyses of urban electricity demand and its vulnerabilities to climate change at regional scales. Model sensitivities to climate perturbations and specific climate change scenarios have been investigated providing first-order estimates of how electricity demand may respond to climatic changes. The results indicate a wide range of electricity demand impacts, with one state experiencing decreased loads associated with climate warming, but the others experiencing a significant increase in annual per capita residential and commercial electricity consumption. The results indicate significantly different sensitivities for neighboring states, suggesting the inability to generalize results. In the long run the non-climatic factors responsible for these differences must be incorporated into the model structure, and assessments of changes in market saturation and related factors need to be included to make it amenable to long range forecasting.

XOBS XREG

Sailor, D. J., & Muñoz, J. R. (1997). Sensitivity of Electricity and Natural Gas Consumption to Climate in the USA - Methodology and Results for Eight States. *Energy*, *22*(10), 987–998.

> A methodology has been developed for assessing the sensitivity of electricity and natural gas consumption to climate at regional scales. The approach involves a multiple-regression analysis of historical energy and climate data, and has been applied to eight of the most energy-intensive states, representing 42% of the total annual energy consumption in the United States. Statistical models were developed using two sets of independent variables--primitive variables such as temperature, relative humidity, and wind speed, and derived variables including cooling degree days, heating degree days, and enthalpy latent days. The advantages and disadvantages of both modeling approaches are discussed in this paper, along with sample results for a combined analysis of residential and commercial consumption in eight states.

XOBS XPRI XPOP XREG

Sanstad, A. H., Johnson, H., Goldstein, N., & Franco, G. (2011). Projecting long-run socioeconomic and demographic trends in California under the SRES A2 and B1 scenarios. *Climatic Change*, *109*(S1), 21–42. doi:10.1007/s10584-011-0296-1

> Emerging and potential future climate change impacts in the state of California will depend substantially on the future evolution of the state’s social structure and economy. To support impact studies, this report describes socioeconomic storylines and key scenario elements for California that are broadly consistent with the global “A2” and “B1” storylines in the 2000 Special Report on Emissions Scenarios of the Intergovernmental Panel on Climate Change, including qualitative socioeconomic context as well as quantitative projections of key variables such as population, urbanization patterns, economic growth, and electricity prices.

XOBS XREG

Sathaye, J. a., Dale, L. L., Larsen, P. H., Fitts, G. a., Koy, K., Lewis, S. M., & De Lucena, A. F. P. (2013). Estimating impacts of warming temperatures on California’s electricity system. *Global Environmental Change*, *23*(2), 499–511. doi:10.1016/j.gloenvcha.2012.12.005

> Despite a clear need, little research has been carried out at the regional-level to quantify potential climate-related impacts to electricity production and delivery systems. This paper introduces a bottom-up study of climate change impacts on California's energy infrastructure, including high temperature effects on power plant capacity, transmission lines, substation capacity, and peak electricity demand. End-of-century impacts were projected using the A2 and B1 Intergovernmental Panel on Climate Change emission scenarios. The study quantifies the effect of high ambient temperatures on electricity generation, the capacity of substations and transmission lines, and the demand for peak power for a set of climate scenarios. Based on these scenarios, atmospheric warming and associated peak demand increases would necessitate up to 38% of additional peak generation capacity and up to 31% additional transmission capacity, assuming current infrastructure. These findings, although based on a limited number of scenarios, suggest that additional funding could be put to good use by supporting R&D into next generation cooling equipment technologies, diversifying the power generation mix without compromising the system's operational flexibility, and designing effective demand side management programs.

XOBS

Scott, M. J., Wrench, L. E., & Hadley, D. L. (1994). Effects of Climate Change on Commercial Building Energy Demand. *Energy Source*, *16*(3).

Most of the studies of the impact of global warming on energy use have employed aggregated utility models and have found that global warming would produce about a 2% decrease in heating requirements per PC and comparable increases in cooling requirements. The one significant exception is a German study that utilized building energy models and determined that the increase in cooling would be somewhat larger, due to the effects of increased humidity with atmospheric warming. This study utilizes the DOE2 building energy model on a prototype commercial building and demonstrates that increased humidity could be a significant factor in total building energy use, particularly in the more humid parts of the United States. The study also demonstrates that the effect can be overcome with advanced building designs.

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XOBS XBEH XEQP

Shipworth, M. (2011). Thermostat settings in English houses: No evidence of change between 1984 and 2007. *Building and Environment*, *46*(3), 635–642. doi:10.1016/j.buildenv.2010.09.009

Rising demand temperatures are widely blamed for UK home energy use not declining over time despite the increased efficiency of dwelling envelopes and heating technologies. The hypothesis that thermostat settings have risen over time is tested using a repeated cross-sectional social survey of owners of centrally heated English houses. No statistical evidence for changes in reported thermostat settings between 1984 and 2007 is found. Why, then, has home energy use not declined over time, despite homes apparently becoming more efficient? There is evidence that the energy efficiency of homes has not improved as much as previously assumed. Improvements in dwelling energy efficiency and increased penetration of central heating would have increased internal temperatures without occupants demanding higher temperatures. Dwelling area heated, or duration of heating, or window opening during the heating season may have increased over time, increasing temperatures or energy use.

XOBS XBEH XPRI

Shipworth, M., Firth, S. K., Gentry, M. I., Wright, A. J., Shipworth, D. T., & Lomas, K. J. (2010). Central heating thermostat settings and timing: building demographics. *Building Research & Information*, *38*(1), 50–69. doi:10.1080/09613210903263007

> Crucial empirical data on central heating demand temperatures and durations are presented. These data are derived from the first national survey of energy use in English homes and includes monitored temperatures in living rooms, central heating settings reported by participants, along with building, technical, and behavioral data. The results are compared with model assumptions with respect to thermostat settings and heating durations. Contrary to assumptions, the use of controls did not reduce average maximum living room temperatures or the duration of operation.

XOBS XBEH

Shorr, N., Najjar, R. G., Amato, A., & Graham, S. (2009). Household heating and cooling energy use in the northeast USA: comparing the effects of climate change with those of purposive behaviors. *Climate Research*, (39), 19–30. doi:10.3354/cr00782

> For most residents in northern temperate zones, the most direct economic impact of global climate change is likely to be changes in home heating and cooling (HC) expenses, estimates of which should be of widespread interest. These residents are increasingly likely to make HC decisions (e.g. switches to electric heat, thermostat settings, conservation investments and behavioral change) in a wider context. The question turns from ‘will projected climate change reduce my HC bills?’ to ‘how will projected climate change, with and without these various actions, affect my HC bills, my total energy use and my greenhouse gas emissions?’ We modeled these 3 variables (HC expense, energy use and GHG emissions) on average households in 13 states in the northeastern United States under projected climate change alone, and under projected climate change with 3 modeled choices: increasing use of air-conditioners (AC); switching from petroleum-derived fuels to electric heating; and investing in insulation and efficiency upgrades. High climate change was projected to reduce annual HC expenses for average households in each state, the effect increasing through the century. These savings varied with ratios of heating degree-day to cooling degree-day changes, and with ratios of petroleum-derivative heating to electric heating households; both ratios varied along a north–south gradient in this region. Increasing AC use increased total energy use and CO2 emissions more than it did expenses. Fuel-switching increased the first 2 more than it reduced the third. Upgrades provided the greatest savings in all 3 variables under low and high climate change. Effective energy policies and effective communication with energy users both require require explicit investigation of HC intensities at the household level, and modeling of conservation behaviors as well as purchased upgrades.

XBEH XPRI

Strengers, Y. (2012). Peak electricity demand and social practice theories: Reframing the role of change agents in the energy sector. *Energy Policy*, *44*, 226–234. doi:10.1016/j.enpol.2012.01.046

> This paper reframes the issue of peak electricity demand using theories of social practices, contending that the problem is one of transforming, technologically-mediated social practices. It reflects on how this body of theory repositions and refocuses the roles and practices of professions charged with the responsibility and agency for affecting and managing energy demand. The paper identifies three areas where demand managers could refocus their attention: (i) enabling co-management relationships with consumers; (ii) working beyond their siloed roles with a broader range of human and non-human actors; and (iii) promoting new practice 'needs' and expectations. It concludes by critically reflecting on the limited agency attributed to 'change agents' such as demand managers in dominant understandings of change. Instead, the paper proposes the need to identify and establish a new group of change agents who are actively but often unwittingly involved in reconfiguring the elements of problematic peaky practices.

XEQP

Tario, J. (2005). *Electric -Powered Trailer Refrigeration Unit Market Study and Technology Assessment*. Rome, New York. Retrieved from http://www.shorepower.com/ElectricPoweredTrailerRefrigeration.pdf

XOBS XREG

Timmer, R. P., & Lamb, P. J. (2007). Relations between Temperature and Residential Natural Gas Consumption in the Central and Eastern United States. *Journal of Applied Meteorology and Climatology*, *46*(11), 1993–2013. doi:10.1175/2007JAMC1552.1

> This study quantifies relations between winter (November–February; December–February) temperature and residential gas consumption for the United States east of the Rocky Mountains for 1989–2000, by region and on monthly and seasonal time scales. State-level monthly gas consumption data are aggregated for nine multistate subregions of three Petroleum Administration for Defense Districts of the U.S. Department of Energy. Two temperature indices [days below percentile (DBP) and heating degree-days (HDD)] are developed using the Richman–Lamb fine-resolution (~1° latitude–longitude) set of daily maximum and minimum temperatures for 1949–2000. Temperature parameters/values that maximize DBP/HDD correlations with gas consumption are identified. Maximum DBP and HDD correlations with gas consumption consistently are largest in the Great Lakes–Ohio Valley region on both monthly (from +0.89 to +0.91) and seasonal (from +0.93 to +0.97) time scales, for which they are based on daily maximum temperature. Such correlations are markedly lower on both time scales (from +0.62 to +0.80) in New England, where gas is less important than heating oil, and on the monthly scale (from +0.55 to +0.75) across the South because of low January correlations. For the South, maximum correlations are for daily DBP and HDD indices based on mean or minimum temperature. The percentiles having the highest DBP index correlations with gas consumption are slightly higher for northern regions than across the South.

XOBS XREG

Tung, C.-P., Tseng, T.-C., Huang, A.-L., Liu, T.-M., & Hu, M.-C. (2013). Impact of climate change on Taiwanese power market determined using linear complementarity model. *Applied Energy*, *102*, 432–439. doi:10.1016/j.apenergy.2012.07.043

The increase in the greenhouse gas concentration in the atmosphere causes significant changes in climate patterns. In turn, this climate change affects the environment, ecology, and human behavior. The emission of greenhouse gases from the power industry has been analyzed in many studies. However, the impact of climate change on the electricity market has received less attention. Hence, the purpose of this research is to determine the impact of climate change on the electricity market, and a case study involving the Taiwanese power market is conducted. First, the impact of climate change on temperature is estimated. Next, because electricity demand can be expressed as a function of temperature, the temperature elasticity of demand is measured. Then, a linear complementarity model is formulated to simulate the Taiwanese power market and climate change scenarios are discussed. Therefore, this paper establishes a simulation framework for calculating the impact of climate change on electricity demand change. In addition, the impact of climate change on the Taiwanese market is examined and presented.

XEQP XREG

U.S. Department of Energy (DOE). (2013). *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather*.

This report—part of the Administration's efforts to support national climate change adaptation planning through the Interagency Climate Change Adaptation Task Force and Strategic Sustainability Planning process established under Executive Order 13514 and to advance the U.S. Department of Energy's goal of promoting energy security—examines current and potential future impacts of these climate trends on the U.S. energy sector. It identifies activities underway to address these challenges and discusses potential opportunities to enhance energy technologies that are more climate-resilient, as well as information, stakeholder engagement, and policies and strategies to further enable their deployment.

XOBS

United States Environmental Protection Agency. (1989). *The Potential Effects of Global Climate Change on the United States*.

To explore the implications of climate change and ways to control it. Congress asked the U.S. Environmental Protection Agency (EPA) to undertake two studies on the greenhouse effect: the first study was to address "The potential health and environmental effects of climate change including, but not be limited to, the potential impacts on agriculture, forests, wetlands, human health, rivers, lakes, estuaries, as well as societal impacts;" and the second study was to examine "policy options that if implemented would stabilize current levels of greenhouse gas concentrations." The second study, "Policy Options for Stabilizing Global Climate," is a companion report to this document.

XOBS

USGCRP (U.S. Global Change Research Program). (2009). *Global Climate Change Impacts in the United States*. (T. R. Karl, J. M. Melillo, & T. C. Peterson, Eds.). Cambridge, UK: Cambridge University Press. Retrieved from http://nca2009.globalchange.gov/

This website is intended to make the 2009 National Climate Assessment ("Global Climate Change Impacts in the United States") more accessible to a variety of interested readers. Several features of this site are prototyping greater traceability of source material, better searchability of the assessment as a whole and enhanced access to images and references. For example, in this 2009 report, you will find links to several supporting datasets, including links from clickable images, a more searchable suite of references, a search function for the entire report, and better linking between chapters.

XOBS

Valor, E., Meneu, V., & Caselles, V. (2001). Daily Air Temperature and Electricity Load in Spain. *Journal of Applied Meteorology and Climatology*, *40*(8), 1413–1421.

Weather has a significant impact on different sectors of the economy. One of the most sensitive is the electricity market, because power demand is linked to several weather variables, mainly the air temperature. This work analyzes the relationship between electricity load and daily air temperature in Spain, using a population-weighted temperature index. The electricity demand shows a significant trend due to socioeconomic factors, in addition to daily and monthly seasonal effects that have been taken into account to isolate the weather influence on electricity load. The results indicate that the relationship is nonlinear, showing a ''comfort interval'' of ±3°C around 18°C and two saturation points beyond which the electricity load no longer increases. The analysis has also revealed that the sensitivity of electricity load to daily air temperature has increased along time, in a higher degree for summer than for winter, although the sensitivity in the cold season is always more significant than in the warm season. Two different temperature-derived variables that allow a better characterization of the observed relationship have been used: the heating and cooling degree-days. The regression of electricity data on them defines the heating and cooling demand functions, which show correlation coefficients of 0.79 and 0.87, and predicts electricity load with standard errors of estimate of ±4% and ±2%, respectively. The maximum elasticity of electricity demand is observed at 7 cooling degree-days and 9 heating degree-days, and the saturation points are reached at 11 cooling degree-days and 13 heating degree-days, respectively. These results are helpful in modeling electricity load behavior for predictive purposes.

XOBS XEQP

Van Ruijven, B. J., Van Vuuren, D. P., De Vries, B. J. M., Isaac, M., Van der Sluijs, J. P., Lucas, P. L., & Balachandra, P. (2011). Model projections for household energy use in India. *Energy Policy*, *39*(12), 7747–7761. doi:http://dx.doi.org/10.1016/j.enpol.2011.09.021

> A bottom-up model for residential energy use that starts from key dynamic concepts on energy use in developing countries is presented and applied to India. Energy use and fuel choice is determined for five end-use functions (cooking, water heating, space heating, lighting and appliances) and for five different income quintiles in rural and urban areas. The paper specifically explores the consequences of different assumptions for income distribution and rural electrification on residential sector energy use and CO_2 emissions, finding that results are clearly sensitive to variations in these parameters. As a result of population and economic growth, total Indian residential energy use is expected to increase by around 65–75% in 2050 compared to 2005, but residential carbon emissions may increase by up to 9–10 times the 2005 level. While a more equal income distribution and rural electrification enhance the transition to commercial fuels and reduce poverty, there is a trade-off in terms of higher CO_2 emissions via increased electricity use.

XOBS XEQP XREG

Wan, K. K. W., Li, D. H. W., Pan, W., & Lam, J. C. (2012). Impact of climate change on building energy use in different climate zones and mitigation and adaptation implications. *Applied Energy*, *97*(0), 274–282. doi:http://dx.doi.org/10.1016/j.apenergy.2011.11.048

> The impact of climate change on energy use in office buildings in a city within each of the five major architectural climates across China was investigated for two emissions scenarios. Space heating is usually provided by oil- or gas-fired boiler plants, whereas space cooling mainly relies on electricity. There would certainly be a shift towards electrical power demand. More energy use in buildings would lead to larger emissions, which in turn would exacerbate climate change and global warming. Energy conservation measures were considered to mitigate the impact of climate change on building energy use. These included building envelope, indoor condition, lighting load density and chiller coefficient of performance. It was found that raising the summer indoor design condition by 1–2 °C could result in significant energy savings and have great mitigation potential.

XOBS XBEH XEQP XREG

Woods, J. (2006). Fiddling with Thermostats: Energy Implications of Heating and Cooling Set Point Behavior. *2006 ACEEE Summer Study on Buildings* (pp. 278–287).

> California's Title 24 Standards assume a certain range of settings and frequency of daily changes in those settings. Until recently, data have not been available to test such assumptions. In 2001-02, the California Energy Commission conducted a demand response experiment that produced unique high-frequency observations of residential thermostat settings and internal temperature measurements, which allow testing of assumptions about thermostat behaviors. Comparing the thermostat settings observed in the California experiment with those commonly assumed in policy modeling indicates that people change cooling and heating set points much more frequently than has been assumed. Frequent set point changes, and the extreme diversity of set point behavior across the population, have significant energy implications. This paper uses Shannon Entropy to assess consistency of thermostat settings, which can produce both higher and lower levels of energy consumption than is conventionally assumed. The findings call into question the benefits of energy efficiency programs that focus on equipment replacement and choice.

XOBS XEQP

Xu, P., Huang, Y. J., Miller, N., Schlegel, N., & Shen, P. (2012). Impacts of climate change on building heating and cooling energy patterns in California. *Energy*, *44*(1), 792–804. doi:10.1016/j.energy.2012.05.013

> This study utilized archived General Circulation Model (GCM) projections and statistically downscaled these data to the site scale for use in building cooling and heating simulations. Building energy usage was projected out to the years of 2040, 2070, and 2100. This study found that under the condition that the cooling technology stays at the same level in the future, electricity use for cooling will increase by 50% over the next 100 years in certain areas of California under the Intergovernmental Panel on Climate Change's worst-case carbon emission scenario, A1F1. Under the Panel's most likely carbon emission scenario (A2), cooling electricity usage will increase by about 25%. Certain types of buildings will be more sensitive to climate change than others. The aggregated energy consumption of all buildings including both heating and cooling will only increase slightly.

XOBS XBEH

Yau, Y. H., & Hasbi, S. (2013). A review of climate change impacts on commercial buildings and their technical services in the tropics. *Renewable and Sustainable Energy Reviews*, *18*, 430–441. doi:10.1016/j.rser.2012.10.035

Climate observations in recent years indicate that the effects of climate change events are apparently having an increasing impact on society. These impacts will likely also affect the building sector. Numerous studies have been conducted to assess future building energy consumption rates. However, these studies often do not take into account climatic variability and consumer reactions towards a temperature shift. A literature review on climate change impacts for commercial buildings and their technical services in the tropics was carried out. This review focuses on the buildings' contributions towards climate change as well as climate change impacts on building structures, changing patterns of energy use and peak demands, building heating and cooling requirements, thermal comfort and emissions impacts. In general, buildings in regions with a predicted increase in temperature will need more cooling and less heating loads. Thus, building energy consumption and carbon emissions are projected to rise during its operational phase. In addition, the erratic weather trends will also affect the building efficiency and sustainability, indoor air quality and thermal comfort. Even though the existing literature on this issue has increased substantially in recent years, there is still a need for further research in tropical climates as the climate change impacts vary with the different seasons, periods and regions.

XOBS XBEH XEQP

Yun, G. Y., & Steemers, K. (2011). Behavioural, physical and socio-economic factors in household cooling energy consumption. *Applied Energy*, *88*(6), 2191–2200. doi:10.1016/j.apenergy.2011.01.010

This paper investigates the significance of behavioural, physical, and socio-economic parameters on cooling energy in order to improve energy efficiency in residential buildings. It demonstrates that such factors exert a significant indirect as well as direct influence on energy use, showing that it is particularly important to understand indirect relationships. An initial study of direct factors affecting cooling energy reveals that occupant behaviour is the most significant issue (related to choices about how often and where air conditioning is used). This is broadly confirmed by path analysis, although climate is seen to be the single most significant parameter, followed by behavioural issues, key physical parameters (e.g. air conditioning type), and finally socio-economic aspects (e.g. household income).

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Zhou, Y., Eom, J., & Clarke, L. (2013). The effect of global climate change, population distribution, and climate mitigation on building energy use in the U.S. and China. *Climatic Change*, *119*(3-4), 979–992. doi:10.1007/s10584-013-0772-x

Climate change will affect the energy system in a number of ways, one of which is through changes in demands for heating and cooling in buildings. Understanding the potential effect of climate change on heating and cooling demands requires taking into account not only the manner in which the building sector might evolve over time, but also important uncertainty about the nature of climate change itself. In this study, we explore the uncertainty in climate change impacts on heating and cooling requirement by constructing estimates of heating and cooling degree days (HDD/CDDs) for both reference (no-policy) and 550 ppmv CO_2 concentration pathways built from three different Global Climate Models (GCMs) output and three scenarios of gridded population distribution. The implications that changing climate and population distribution might have for building energy consumption in the U.S. and China are then explored by using the results of HDD/CDDs as inputs to a detailed, building energy model, nested in the long-term global integrated assessment framework, Global Change Assessment Model (GCAM). The results across the modeled changes in climate and population distributions indicate that unabated climate change would cause building sector's final energy consumption to decrease modestly (6 % decrease or less depending on climate models) in both the U.S. and China by the end of the century as decreased heating consumption more than offsets increased cooling using primarily electricity. However, global climate change virtually has negligible effect on total CO_2 emissions in the buildings sector in both countries. The results also indicate more substantial implications for the fuel mix with increases in electricity and decreases in other fuels, which may be consistent with climate mitigation goals. The variation in results across all scenarios due to variation of population distribution is smaller than variation due to the use of different climate models.

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